Stories from the classroom: using pupils' questions to develop science teachers' learning

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ABSTRACT Pupils' questions can play a powerful role in helping them to develop conceptual understanding, but can also provide a stimulus for teacher learning. This article presents a series of stories that illustrate the challenges of capitalising on pupils' questions, given the complexity of decision-making required in the science classroom and the current accountability pressures that teachers experience. The project highlights the crucial role that teacher educators and mentors can play, as 'critical colleagues' for early-career science teachers, in encouraging and opening up opportunities for teacher learning in the classroom.

Introduction

The recently published report reviewing initial teacher training (ITT) in England (Carter, 2015) emphasised the relationships between teachers' subject knowledge and effective teaching. The report recommended that both subject knowledge and, what it refers to as, subject-specific pedagogy are incorporated into a framework for ITT content.

The Carter report itself drew on a meta-study by Coe *et al*. (2014), which highlighted teachers' subject knowledge as one of the key factors in improving pupil attainment. However, the importance of subject knowledge is also a contentious area, as illustrated by recent debates over the relaxation of the requirement for qualified status for teachers to supposedly free up schools to employ 'subject experts'. Coe *et al*. (2014) highlights that the evidence for links between degree class and teacher effectiveness is limited and inconsistent; a first-class degree is no guarantee that you can excel at the complex decision-making demanded by the science classroom. Loughran (2006) made this point clear in stating, '*professional learning is not developed through simply gaining more knowledge, rather, professional learning is enhanced by one becoming more perceptive to the complexities, possibilities and nuances of teaching contexts*' (p.136).

There is an 'accepted wisdom' (Kind, 2009: 1531) that science teachers are more effective if they teach within their own subject specialism because it is believed a degree instils in teachers expertise in, and enthusiasm for, that subject. Yet the development of science teachers' knowledge for teaching is in reality a complex, constantly evolving process, heavily influenced by teachers' own prior learning experiences. Knowledge of conceptual progression, along with common misconceptions and what students find difficult, are key components of what Shulman (1986) called pedagogical content knowledge (PCK). These aspects can inform teachers' planning and help them to anticipate what might occur during a lesson. Development of these areas of knowledge is an important dimension of initial teacher education programmes, but, unless trainees are helped to apply and contextualise their knowledge in their classroom, such knowledge will remain in the abstract. Teachers at an early stage of their careers are understandably focused on the 'delivery of their plan' and organisational aspects of their lessons, and hence can struggle to notice pupils' responses or to make sense of unexpected questions that could be used to deepen conceptual understanding. Yet, even when teachers have gained experience, so affording them the opportunity to 'notice' critical responses and questions from pupils, it can be difficult to apply their specialised subject knowledge in a way that capitalises on the opportunity (Hattie, 2002). Such questions are inevitably unsettling and this article describes a project that sought to support early-career science teachers in recognising the contingent value of these questions and using them to further their own learning and that of their pupils.

Background

The classroom stories in this article are drawn from a research project in which I am engaged as a teacher educator. My primary role is that of a PGCE tutor, but the increased expectation for those involved in initial teacher education to adopt a support role with newly qualified teachers (NQTs) opened up positive opportunities to work with the latter. The project is seeking to capture the experience of early-career teachers in teaching key science concepts and develop ways of supporting their professional learning. Lessons are filmed or audio-recorded so that post-lesson discussion can be stimulated through replaying phases of the lesson; teachers are encouraged to focus on the pupils and particular responses they gave or questions that they asked.

Surveys of science NQTs have shown them to think that they have gained their knowledge for teaching from their science degree and from their one-year PGCE training; this knowledge is viewed as fixed and ready for enacting in their first teaching post (Berry *et al.*, 2013). Professional development courses for NQTs tend to focus on generic aspects of a teacher's practice, for example differentiation or assessment, and few NQTs identify subject knowledge development as a priority for their early-career CPD. Even where it was cited as a priority there was very little clarity over how subject development might take place (Berry *et al.*, 2013). Yet NQTs need to be supported in deepening their own conceptual understanding and developing their 'knowing how to act/respond' in the classroom.

The stories have been selected in part because they cover a range of different topics, involving pupils of different ages and abilities, but above all because they provide inspiration and new ways of looking at conceptual ideas. It is hoped that the stories might help school mentors, particularly those who have responsibility for NQTs, and teacher educators to work with early-career teachers in enabling them to reflect and notice in the classroom, making use of pupils' unexpected questions. This isn't about teachers' lack of knowledge, as all those involved were highly qualified, but about teachers finding different ways of dealing with the complex interactions that take place in the classroom.

Classroom stories

Story 1: Chloe and year 8

Chloe was teaching a year 8 lesson (ages 12–13) geared to helping pupils to apply particle theory ideas to changes of state. The pupils engaged with the modelling activities and practical tasks, and towards the end of the lesson Chloe came up to me, unsure of how to respond to a pupil's question: '*Why does paper burn and not melt? Can you get liquid paper?*' On one level, her struggle to deal with this question is surprising as she would have had knowledge of the chemical structure of paper, but this illustrates the challenges of enacting such knowledge in the heat of the moment. We briefly discussed the concepts involved and Chloe then returned to the pupil, starting a discussion that encouraged the latter to think about other experiences of heating substances. After the lesson we reflected on the fact that changes of state and chemical reactions (here decomposition and combustion) are often taught separately, and, hence, individuals can proceed through school and university without ever having made links on a particulate level between these important concepts. Chloe herself probably fell into that category and so this incident enabled her to view her own conceptual understanding in a new way. And what if I had not been there? Well, Chloe admitted that she was shocked by the question and might well have sidestepped it, seeing it as a distraction from her intentions for the lesson. A reaction along the lines of '*Interesting question – why don't you research that?*' might have been articulated, rather than any attempt being made to engage the pupil in thinking about the question. In post-lesson reflection, Chloe

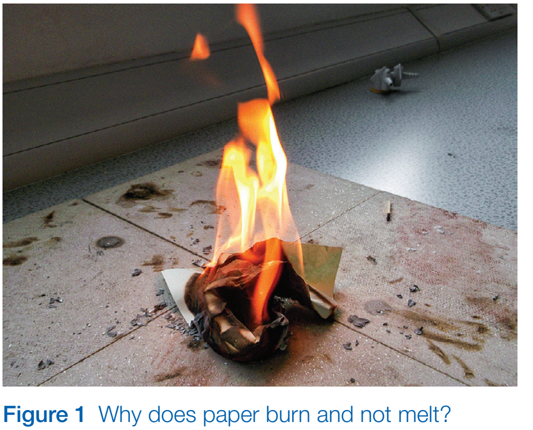

Figure 1 Why does paper burn and not melt?

stated how good the question was in stimulating thinking as neighbouring pupils had been drawn into the discussion. She then intended in the next lesson to pursue the question with the whole class, using a 'shared enquiry' pedagogical approach.

Story 2: Rachel and year 9

During a year 9 lesson (ages 13–14) on metal reactivity, pupils were to carry out a practical activity to investigate how a number of metals reacted with water. By way of introduction, Rachel demonstrated the reaction of calcium with water, partly for safety reasons as the reaction is quite vigorous, and also to model the observing and inferring processes that she wanted pupils to undertake. Pupils were engaged by the visible nature of the reaction and Rachel asked questions to elicit ideas relating to hydrogen being produced and the exothermic status of the reaction. Just as pupils were about to move back to their places, a pupil suddenly asked, '*How come the calcium in our teeth doesn't react like that when we drink water?*' Rachel struggled to think in the moment and responded with '*well the calcium is not the same in our teeth*', in a manner that rather closed the conversation down and left the pupil looking somewhat puzzled.

Post-lesson discussion with Rachel involved us sketching out a concept map that illustrated the concepts that might link to the topic of metal reactivity. This exercise helped her consider how she might have built on her '*calcium is not the same in our teeth*' statement by exploring the concepts of element (which she'd been demonstrating), compound (calcium phosphate in teeth), and the differences between them. It also opened up language issues; after all, we do talk about '*needing calcium to have healthy teeth*', and other misconceptions, such as that saliva doesn't contain water. Rachel is not a chemistry specialist, but it was not evident that having a chemistry degree would have necessarily helped her to capitalise on the unexpected question in a different way.

Story 3: Jen and year 10

During a year 10 (ages 14–15) biology lesson Jen was working with pupils on developing their understanding of interdependence of organisms and energy transfer. The lesson was linked back to previous work, including practical activities, on photosynthesis and the concept of plants making their own food. Pupils were also shown pictures of food to remind them that they are stores of energy; they had to sequence, for example, a selection of foods in order of their energy values.

Quite near the end of the lesson a pupil, seemingly not very engaged for most of the lesson, turned to me as observer and asked '*so, if plants contain all this energy, why don't we eat them?*' On the one hand the question is profound but on the other reveals the lack of connections in that pupil's thinking. I directed them to repeat the question to Jen, so that she could perhaps use it with the whole class in constructing new understanding. Jen admitted afterwards that she shied away from doing so, fearing that she would articulate a response that might make them look silly, even though they may well have been expressing what many could have been thinking or might think if prompted. Hence the question was handed back to me and

Figure 2 Why doesn't the calcium in our teeth react with water?

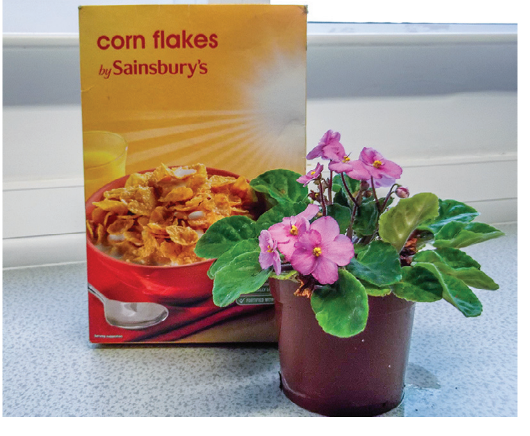

Figure 3 Why don't we eat plants if they contain all this energy?

I had a conversation around the pupil's breakfast (cornflakes!), so providing a context to link ideas about plants and our energy requirements. This scenario illustrates well the complex decision-making that has to take place in the classroom and the potential discomfort that these unsurprising situations can trigger. Jen made a judgement based primarily on her justifiable concern for the boy's emotional wellbeing, but found it challenging to respond in a way that creatively used his question to develop the understanding of the whole class.

Story 4: Tom and year 7

Tom was teaching a high-attaining year 7 group (ages 11–12) and nearing the end of a series of lessons on the particle theory. This particular lesson had the key aim of 'applying the particle theory' and pupils were to rotate around a carousel of activities that would engage them with various phenomena that could be related to particles, for example trying to compress water in a syringe and adding salt to water. Pupils were encouraged to represent their ideas diagrammatically and, as a reminder, a particle diagram was drawn on the board. At this point a girl interrupted the lesson flow to ask, '*so do sand and gold have the same size particles?*' One sensed that at this juncture the question was perceived as inconvenient because early work with the particle theory places emphasis on representing particles as being the same size. This approach is taken within the context of state changes, though often solid/liquid/gas diagrams are not linked to any particular substance and pupils may well be left thinking that all particles are the same size.

In the lesson Tom reacted to the question by stating that gold and sand did have differently sized particles, and that this was something that would be returned to in year 8. He quickly reiterated that, for the carousel of activities that they would be doing, particles should be drawn as having the same magnitude and they should not worry about them sometimes having different sizes. When asked about the incident afterwards, Tom accepted that he felt a tension when the question was posed between wanting to use the question with the whole class, fear of making things 'overly complex' at this early stage, and the simple pragmatic factor of ensuing discussion taking up time that was needed for completion of the practical activities. We talked about the explanatory use of the particle theory and that its fundamental purpose is to help us explain the properties of materials. Gold behaves very differently to sand and if both are made up of 'particles' then there must be something different about those particles and their arrangement. The question asked was a very legitimate one, but at that instant Tom understandably could not find a route through his conflicting options to accommodate the question in the flow of the lesson.

Figure 4 Do sand and gold have the same size particles?

Story 5: Matthew and year 8

The final story also relates to particle size. Matthew was teaching a year 8 group (ages 12–13) that had struggled in previous lessons with applying the particle theory to a range of phenomena, so wanted to consolidate the concepts that particles were very small and that all materials contained a huge number of them, and then move on to explaining dissolving in a particulate way. The following dialogue illustrates the problems that the group continued to have with the first two concepts. Matthew was holding up a flask of water in front of the class.

Matthew: *What's inside here?*

Pupil: *Water.*

Matthew: *What's water?*

Pupil chorus: *H_2O.*

One pupil adds: *2 hydrogen and 1 oxygen.*

Matthew: *So how many H_2Os are in here?*

Pupils: *1, 3, 2?*

Matthew: *How many H_2Os are there?*

Pupils: *3, 2, 6, none?* [Matthew looked despairingly at the water]

At this point Matthew provided some input using a periodic table and then returned to questioning the pupils about the water:

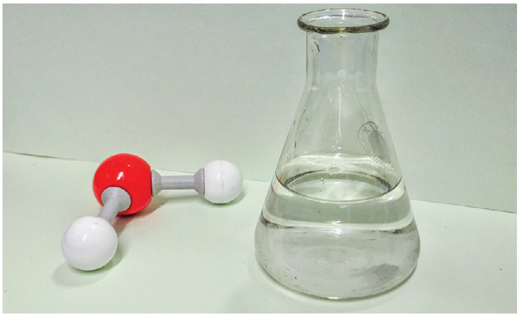

Figure 5 Are there 'bare' molecules of water in there?

Matthew: *Can you see any of them* [the particles] *in the water?*

Pupils: *No.*

Matthew: *So how many of them?*

Pupils: *None, hundreds?*

Matthew: *Hundreds?*

Pupils: *Thousands, millions?*

Pupil: *So sir, are there 'bare' molecules of water in there?*

'Bare' is urban slang for the concept of 'many' or 'loads of', and the way that Matthew looked quizzically across the room at me indicated that this was new to him. I nodded positively and made encouraging facial gestures, and this seemed to provide him with the trigger to recognise the potential value of the question and explore 'bare molecules' further. He actually started to use the term in his dialogue about the water but managed to do so in way that amused the pupils without them viewing him as trying to be overly cool and hip! Afterwards Matthew reflected that he still felt wrong-footed by the question, which raises interesting points about the scientific dialogue that pupils experience in lessons and how at times it will be as nonsensical to them as the term 'bare' was to Matthew. He was willing to act though in response to this unforeseen question and was then able to use it to help the pupils develop their understanding about particle theory. His readiness to change his dialogue at that point could be seen to be critical in both holding pupils' attention and encouraging their participation in the discussion.

Discussion

Each narrative has its own distinct nature, influenced by the context of the specific science classroom, but there are some commonalities across these five stories. All contain an unexpected question from a pupil that enabled a reaction from the teacher and evoked emotions of surprise and discomfort. It is encouraging, however, that pupils were asking such questions because it indicates that they have been thinking about the ideas presented in these lessons and have been trying to link them with other things they know. For example, in Story 1 the pupil was trying to link his varied experiences of how different substances behave when heated. However, such questions pose a considerable challenge for new teachers as they require a flexible response that will extend pupils' thinking and maintain coherence in the lesson.

There was a range of awareness from the teachers that something was perhaps missing in their responses to the pupils' questions and of how useful the questions might have been. In Story 4 the question about relative size of particles in gold and sand is viewed as something of a distraction and the teacher felt unwilling to deviate from their plan for the lesson. In Story 3, where some might view the question asked about plants and energy as revealing ignorance, even though it has a profound dimension, Jen's care for pupils' wellbeing and perhaps her own categorisation of the question as one of ignorance, means that she was less willing to acknowledge the critical nature of such a question. In addition to recognising the potential value of questions, teachers at this early stage of their careers have to be willing to acknowledge the complexity of the classroom and make changes to accommodate pupils' interests and concerns, often expressed through questions. In many of these stories the question indicates that an issue really concerns the pupil: that paper doesn't melt when heated, that our teeth don't react vigorously with water, that plants could supply us with energy.

The stories reveal the potential of pupils' questions for developing teachers' learning and pupils' conceptual understanding. Part of the challenge for early-career teachers is developing that willingness to act and respond flexibly in the classroom when there are accountability pressures, perceived or otherwise, from a prescriptive curriculum and inspection regimes that often fail to recognise the complexity of the classroom. Therefore, a key role for science teacher educators and mentors would be to provide some shielding from those pressures, helping teachers to notice and value critical questions and to develop a willingness to deviate from their plans.

The power of such questions for generating critical reflection about teaching and learning has been highlighted (Watts *et al.,* 1997), and can lead to shifts in teachers' thinking and practice. Such reflection is also an important dimension in development of the subject-specific pedagogy to which Carter (2015) refers. Teacher reflection in this area is often characterised as being idiosyncratic in nature, and its development as highly context and topic specific (Van Driel, Verloop and de Vos, 1998). These classroom stories illustrate well the idiosyncrasy of individual teachers' practices and their interactions in the classroom, that there is no set qualification or knowledge that will necessarily help them to respond to pupils' questions in ways that deepen conceptual understanding. It is here then that teacher educators and mentors can play an important part in enabling early-career teachers to unpack the significance of questions asked by pupils in the science classroom. This project and its stories have illustrated the value of having an experienced colleague in the classroom, not as an assessor or observer, but as someone who themselves is perceptive to the classroom's complexities and subtleties and to the opportunities for teacher learning that are present. Participation in the lesson would seem to be important, however seemingly subtle, as in Story 5 we see how an encouraging look from me was sufficient to trigger Matthew's response to 'bare molecules'. Helping teachers to reason about their decision-making 'in the moment' and to make connections between critical questions and previous experiences or educational theory should also be features of such mentoring. The project has revealed the potential for teacher educators and mentors to have a role as 'critical colleagues' in the classroom during a science teacher's NQT year. While enjoying the freedom from the often intense scrutiny of a PGCE year, all the participants in this project regretted the absence of feedback that focuses on conceptual understanding of science. The provocative and unexpected questions that pupils ask can provide a vital stimulus for such development work.

Conclusion

The questions asked by pupils in these stories are authentic and novel, possessing a transformative power, even if they were often difficult to notice and respond to. All the questions provided a stimulus for rich discussion and teachers at this early stage of their careers should be encouraged to foster learning environments that give pupils the freedom to express their concerns and frustrations through questions. The engagement with those sometimes unsettling questions can provide a means for professional learning and development of practice; however, teachers need support in recognising such situations and enacting the complex decision making that the science classroom demands.

References

Berry, B., James, J., Rivett, A. and Wharf, M. (2013) *Identifying Subject-Knowledge Gaps and CPD Needs of Early Career Teachers*. Report by the Science Learning Centre South West for the Research, Impact & Accreditation Group of the Science Learning Centre Network.

Carter (2015) *Carter Review of Initial Teacher Training*. DfE report: DFE-00036-2015. Available at: www.gov.uk/government/publications/carter-review-of-initial-teacher-training.

Coe, R., Aloisi, C., Higgins, S. and Major, L. E. (2014) *What Makes Great Teaching? Review of the Underpinning Research*. Sutton Trust report.

Hattie, J. (2002) What are the attributes of excellent teachers? In *Teachers Make a Difference: What is the Research Evidence?* ed. Webber, B. pp. 3–26. NZCER.

Kind, V. (2009) A conflict in your head: an exploration of trainee science teachers' subject matter knowledge development and its impact on teacher self-confidence. *International Journal of Science Education,* **31**(11), 1529–1562.

Loughran, J. J. (2006) *Developing a Pedagogy of Teacher Education: Understanding Teaching and Learning about Teaching*. London: Routledge.

Shulman, L. S. (1986) Those who understand: knowledge growth in teaching. *Educational Researcher*, **15**(2), 4–14.

Van Driel, J. H., Verloop, N. and de Vos, W. (1998) Developing science teachers' pedagogical content knowledge. *Journal of Research in Science Teaching*, **35**(6), 673–695.

Watts, M., Alsop, S., Gould, G. and Walsh, A. (1997) Prompting teachers' constructive reflection: pupils' questions as critical incidents. *International Journal of Science Education*, **19**(9), 1025–1037.

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